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Generation Demand Balance Analysis for Uganda-Vision 2040

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Abstract
Uganda's Vision 2040 establishes a target of 52 GW of installed electricity generation capacity by 2040, an objective that demonstrates a significant divergence from current growth projections. This study utilises a quantitative methodology, employing econometric and time-series models to forecast electricity demand, peak loads, and installed capacity through 2040. Sector-specific consumption data from 2013 to 2023, alongside key socio-economic drivers, were used to develop log-linear regression models for energy demand and a harmonic regression model for peak demand. Under the base-case scenario, 2040 annual energy demand is projected to reach approximately 14,320 GWh, with a peak demand of 2,291 MW, and an installed capacity of 3,381 MW. These forecasts account for only 6% of the Vision 2040 capacity target. This substantial mismatch between the ambitious national objective and data-driven projections underscores the critical need for evidence-based planning to mitigate the risks of stranded assets, financial inefficiency, and unsustainable development. The findings advocate for a phased, demand-driven approach to generation expansion to ensure a reliable and economically viable energy future for Uganda.

Keywords: Generation-Demand Balance; Electricity Forecasting; Uganda Vision 2040; Econometric Modelling; Energy Policy; Sustainable Development; Sub-Saharan Africa

Introduction
Uganda's Vision 2040 provides a strategic framework to guide the nation's transformation into a competitive upper-middle-income economy, an objective intrinsically linked to the robust expansion of its energy infrastructure. A central pillar of this vision is the ambitious target to achieve 52 GW of installed electricity generation capacity by 2040, designed to support a projected per capita consumption of 3,668 kWh. This represents a monumental leap from the country's current status, where installed capacity was below 2 GW and annual electricity demand was approximately 4,500 GWh as of 2023. This research addresses the critical problem of a potential and significant incongruity between Uganda's ambitious generation goals and the actual, evidence-based trajectory of its demand growth. Such a mismatch poses a dichotomous risk: either the creation of stranded generation assets, wherein significant capital investment remains underutilised, or the emergence of energy deficits that could severely impede national development.

This study is justified by the urgent need for a quantitative, data-driven assessment of Uganda's long-term energy outlook. To address this, the paper first analyses historical electricity consumption from 2013 to 2023 to identify the principal drivers of demand. It then develops and validates sector-specific, statistically robust demand forecasting models to project future energy demand and installed capacity under multiple growth scenarios. Finally, it critically analyses the projected generation-demand balance against the Vision 2040 targets to inform national policy and strategic energy planning. The Ugandan electricity sector is currently dominated by hydropower, which accounts for the vast majority of its installed capacity of approximately 1.8 GW. While the country possesses significant untapped potential in renewable sources like solar and geothermal, the government's long-term strategy also includes the ambitious introduction of nuclear power, envisioned to contribute up to 24,000 MW. As previous demand forecasts for Uganda have varied, this study contributes an updated, long-term analysis that explicitly models the generation-demand balance against the Vision 2040 target, using the most recent data available.

Accurate long-term electricity demand forecasting is a cornerstone of strategic planning for future infrastructure. Methodologies are broadly categorised into econometric, time-series, and artificial intelligence (AI) approaches. Econometric models, such as the log-linear regression used in this study, employ statistical techniques to quantify the relationship between electricity consumption and explanatory variables like GDP and population. Their strength lies in their explanatory power and utility for scenario analysis, with the log-linear form being particularly advantageous as its coefficients can be interpreted as elasticities. In contrast, time-series models are effective for extrapolating historical patterns but do not explain the causal factors behind the forecasts. While advanced AI techniques can capture complex non-linear relationships, their application for long-term forecasting in data-scarce environments like Uganda is challenging due to their large data requirements and "black-box" nature, which can obscure the interpretation of results.

Methodology

This study employed a quantitative methodology to analyse and forecast Uganda's generation-demand balance through 2040, executed within the Python programming environment.

Data Acquisition and Preparation

A comprehensive dataset spanning from Q1 2013 to Q4 2023 was compiled from official sources, including the Electricity Regulatory Authority (ERA), Uganda Bureau of Statistics (UBOS), and the World Bank. The dataset included quarterly electricity consumption in GWh for the Domestic, Commercial, Medium-Industrial, and Large-Industrial sectors. It also contained socio-economic drivers such as GDP per capita, sectoral GDP, population, and national electrification rates. Finally, system data on annual installed generation capacity (MW) and monthly peak demand (MW) were collected.

Annual data were converted to quarterly frequency using cubic spline interpolation. All variables underwent a natural logarithmic transformation to stabilise variance and enable the interpretation of regression coefficients as elasticities. A time trend variable was created, and lagged demand variables (Demand_t-1) were generated to capture persistence effects in consumption.

Forecasting Models

The study utilised three types of forecasting models. For energy demand, sector-specific demand was modelled using a multiple log-linear regression framework with the general structure:

$$\ln(\text{Demand\_t}) = \beta_0 + \Sigma\beta_i \ln(\text{Driver}_i, t) + \beta_t \text{Time}_t + \beta_l \ln(\text{LaggedDemand\_t-1}) + \varepsilon_t \quad \textit{Equation 1}$$

Model parameters were estimated via Ordinary Least Squares (OLS) with a stepwise backward elimination procedure to retain only statistically significant predictors ($p < 0.05$), ensuring a parsimonious model. For peak demand, a harmonic regression model was used to forecast monthly peak demand, designed to capture strong seasonal patterns through a linear time trend and sinusoidal terms for annual and semi-annual cycles. For installed capacity, future capacity was projected using Holt's exponential smoothing, a time-series method well-suited for data exhibiting a distinct linear trend, as observed in Uganda's historical capacity additions.

Model Validation and Diagnostics

The predictive accuracy of all models was evaluated using an out-of-sample validation strategy. Data from 2013-2022 was used for training, while 2023 data served as a holdout set for testing. Performance was measured using Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE). Furthermore, a suite of diagnostic tests was conducted on the final regression models to ensure their statistical validity. These tests confirmed the normality of residuals, homoscedasticity (constant variance), and absence of significant autocorrelation, thereby satisfying the core assumptions of OLS regression. The econometric models were also benchmarked against LSTM and XGBoost machine learning models to confirm their suitability for this long-term forecasting task.

Scenario Definition

Three growth scenarios (Slow, Base, and High) were formulated to account for macroeconomic uncertainty. The **Base Scenario** utilised historical Compound Annual Growth Rates (CAGRs) for the drivers observed between 2013-2023 (e.g., GDP per capita at 3.5%, Population at 2.8%). The **Slow and High Scenarios** were defined by applying a ±20% variation to these baseline growth rates. This range was chosen as it is a common and robust practice in long-term energy modelling for sensitivity analysis, creating a plausible envelope of future outcomes that accounts for potential optimistic and pessimistic deviations from the baseline.

Results and Analysis

Historical Trends and Model Performance

From 2013 to 2023, the Large Industrial sector was the principal driver of demand, exhibiting the highest CAGR of 8.61%. The developed log-linear econometric models demonstrated high predictive accuracy, achieving an aggregate MAPE of 1.86% on 2023 holdout data. This performance significantly surpassed that of benchmark machine learning models like LSTM (5.17% MAPE) and XGBoost (11.22% MAPE). The harmonic regression model for peak demand was similarly robust, yielding a MAPE of 1.82%.

Analysis of the harmonic model's coefficients revealed that the Time trend and the primary annual cosine term (cos1) were statistically significant ($p < 0.05$), confirming their critical roles in capturing the consistent upward trend and seasonal patterns in peak demand.

Table 1 presents the mean, minimum, maximum, and Compound Annual Growth Rate (CAGR) for electricity consumption in GWh for the Domestic, Commercial, Medium Industrial, and Large Industrial sectors from 2013 to 2023. It highlights the dominance and rapid growth of the Large Industrial sector.

Table 1 Summary Statistics and CAGR of Historical Annual Energy Demand by Sector (2013-2023)

Sector	mean	min	max	CAGR_%
Domestic	661.93	476.13	915.48	6.76
Commercial	348.88	255.41	464.36	6.16
MediumIndustrial	461.68	378.34	590.58	4.55
LargeIndustrial	1536.20	980.14	2238.52	8.61

Figure 1 visualises the annual electricity demand in GWh for each of the four sectors from 2013 to 2023. The plot clearly shows the steep upward trajectory of the Large Industrial sector compared to the more modest growth in the other sectors.

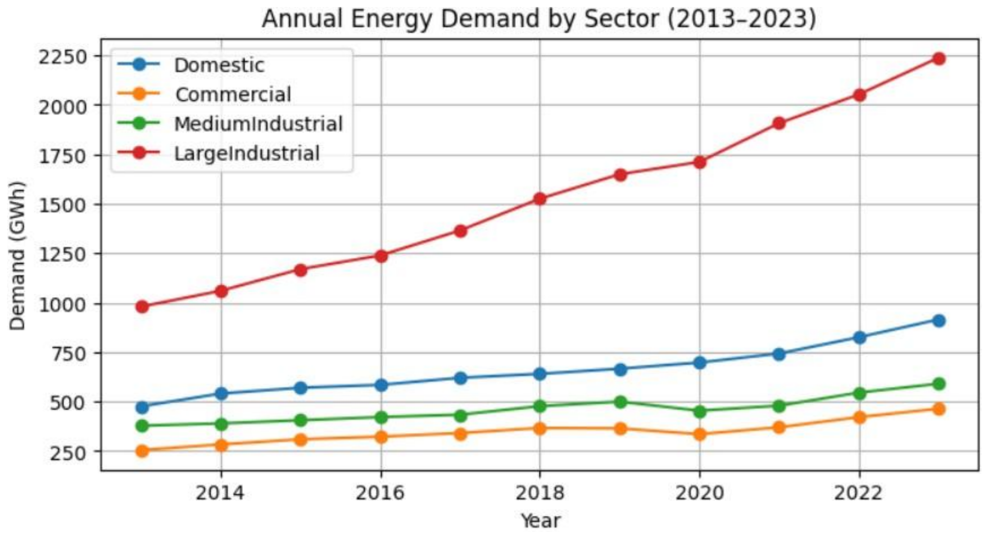

Fig. 1: Historical Trend of Annual Energy Consumption (GWh) by Sector

Figure 2 displays the results of an additive time-series decomposition of total quarterly electricity demand. It is composed of four subplots: the observed data, the extracted long-term trend, the recurring seasonal pattern, and the residual (irregular) component. It visually confirms the consistent upward trend and the distinct quarterly seasonality in demand.

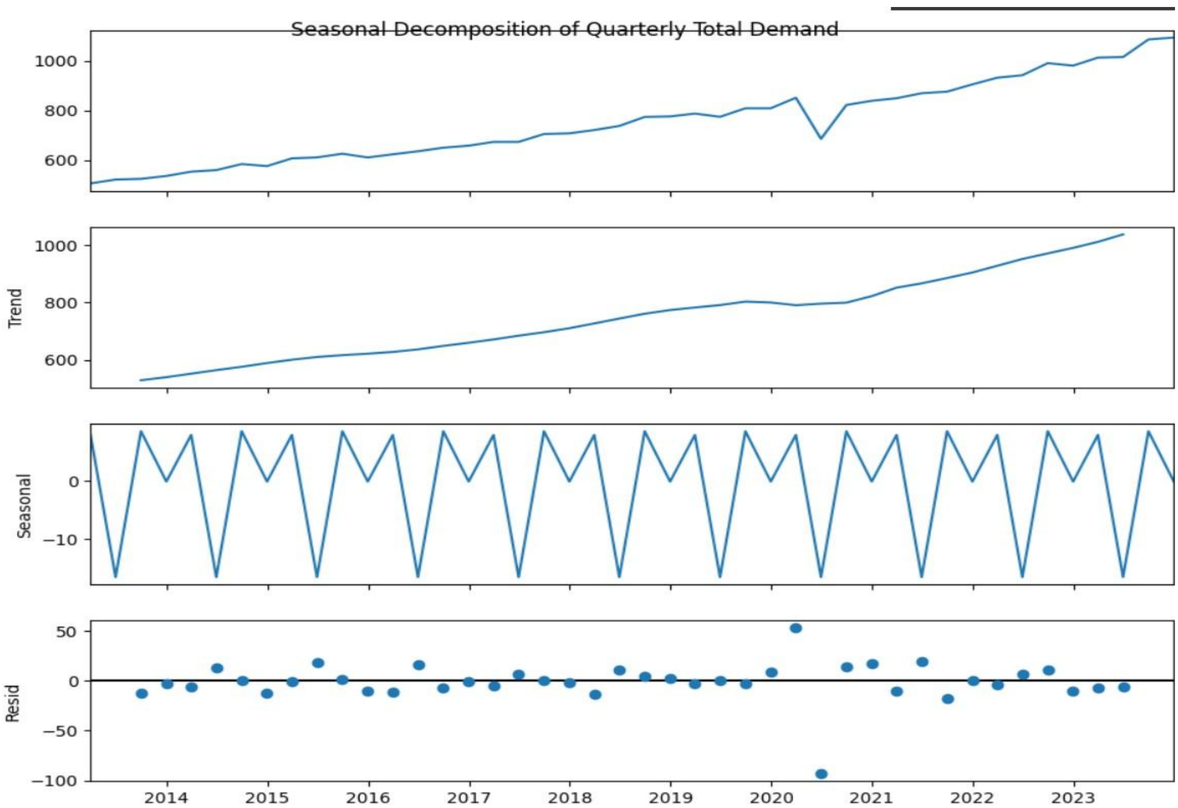

Fig. 2: Seasonal Decomposition of Quarterly Total Electricity Demand

Table 2 details the final regression equations for each of the four demand sectors after the stepwise elimination procedure. It lists the statistically significant predictor variables (e.g., lagged demand, GDP, population, time trend) for each sector, providing insight into the key drivers of consumption.

Table 2: Final Log-Linear Regression Model Specifications for Each Sector

Variable	p_value	Sector	Final_Formula
Intercept	0.0011	Domestic	$\ln(Domestic_t) = \beta_0 + \beta_1 \cdot \ln(Domestic_{t-1}) + \beta_2 \cdot Time_t + \varepsilon_t$
log_Domestic_Lag1	0.0022		
Time	0.0015		
Intercept	0.0028	Commercial	$\ln(Commercial_t) = \beta_0 + \beta_1 \cdot \ln(Commercial_{t-1}) + \beta_2 \cdot \ln(GDP\_pc_t) + \beta_3 \cdot \ln(GDP\_i_t) + \beta_4 \cdot \ln(Population_t) + \varepsilon_t$
log_Commercial_Lag1	0.0127		
log_GDP_pc	0.0058		
log_GDP_i	0.0063		
log_Population	0.0035		
Intercept	0	LargeIndustrial	$\ln(LargeIndustrial_t) = \beta_0 + \beta_1 \cdot \ln(GDP\_i_t) + \beta_2 \cdot Time_t + \varepsilon_t$
Time	0		
log_Commercial_Lag1	0.0127	MediumIndustrial	$\ln(MediumIndustrial_t) = \beta_0 + \beta_1 \cdot \ln(GDP\_pc_t) + \beta_2 \cdot \ln(GDP\_i_t) + \beta_3 \cdot \ln(Population_t) + \beta_4 \cdot ElecDiff4_t + \varepsilon_t$
log_GDP_pc	0.0058		
log_GDP_i	0.0063		
log_Population	0.0035		
Intercept	0.0003		

Table 3 compares the predictive accuracy of the final econometric (log-linear) models against two machine learning models (LSTM and XGBoost) using 2023 holdout data. It presents the Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE) for each model, demonstrating the superior performance of the econometric approach for this study.

Table 3: Comparative Performance Metrics of Forecasting Models

Model Comparison & Validation Metrics						
	Econometric Regression Model		**LSTM Model**		**XGBoost Model**	
Sector	*MAPE (%)*	*RMSE (GWh)*	*MAPE (%)*	*RMSE (GWh)*	*MAPE (%)*	*RMSE (GWh)*
Domestic	5.51	15.83	5.99	18.32	12.88	33.97
Commercial	4.45	5.26	5.21	7.11	12.24	15.19
MediumIndustrial	2.46	4.87	4.28	6.87	10.67	16.29
LargeIndustrial	1.06	7.93	5.01	30.33	10.17	59.73
Overall	***1.86***	***22.5***	***5.17***	***60.27***	***11.22***	***125.27***

Long-Term Forecasts and Generation-Demand Balance

Under the **Base Scenario**, annual electricity demand is projected to grow from ~4,500 GWh in 2024 to **14,320 GWh** by 2040. Installed capacity is projected to increase to **3,381 MW** over the same period, with peak demand reaching **2,291 MW**.

A substantial gap exists between these data-driven forecasts and the Vision 2040 objectives. The forecasted 2040 energy demand of 14,320 GWh constitutes only 6.3% of the 227,760 GWh energy equivalent produced by a 52 GW system (at 50% capacity factor). Similarly, the projected 2040 installed capacity of 3,381 MW represents only 6.5% of the 52 GW target.

Table 4 presents the year-by-year forecast of total annual electricity demand in GWh through 2040 under the three defined scenarios: Slow, Base, and High. It quantifies the range of potential future demand based on different socio-economic growth assumptions.

Table 4: Projected Total Annual Energy Demand (GWh) from 2024 to 2040

Year	Slow (GWh)	Base (GWh)	High (GWh)
2024	4497.89	4516.18	4535.01
2025	4785.95	4821.48	4858.56
2026	5120.11	5174.35	5231.74
2027	5481.05	5556.22	5636.85
2028	5869.43	5967.97	6075.14
2029	6287.32	6411.89	6549.23
2030	6737.01	6890.5	7062.09
2031	7221	7406.58	7616.91
2032	7741.99	7963.1	8217.19
2033	8302.89	8563.29	8866.7
2034	8906.86	9210.64	9569.55
2035	9557.32	9908.94	10330.2
2036	10257.96	10662.27	11153.49
2037	11012.77	11475.07	12044.68
2038	11826.07	12352.12	13009.47
2039	12702.54	13298.61	14054.05
2040	13647.24	14320.15	15185.15

Figure 3 shows the three annual energy demand forecast scenarios (Slow, Base, High) from 2024 to 2040. A horizontal line representing the 227,760 GWh energy equivalent of the 52 GW target is included at the top, visually illustrating the immense gap between projected demand and the national goal.

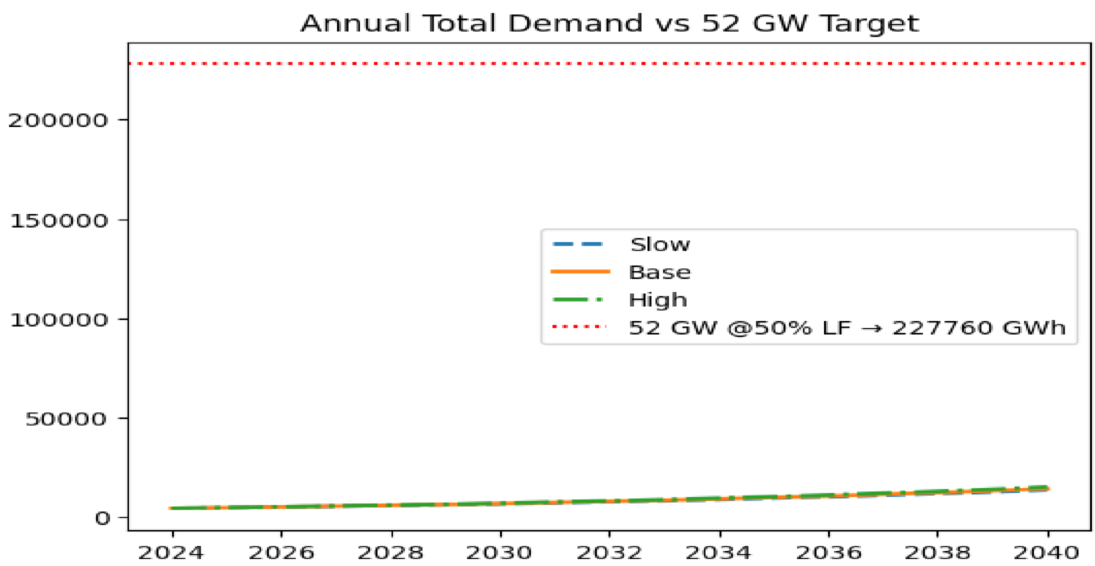

Fig. 3: Chart of Forecasted Annual Energy Demand Scenarios vs. Vision 2040 Target

Table 5 provides a year-by-year comparison from 2024 to 2040 of the forecasted annual maximum peak demand (MW), the projected installed capacity (MW), and the resulting Planning Reserve Margin (PRM) in per cent. It demonstrates that while the reserve margin remains adequate, it declines over time.

Table 5: Comparison of Forecasted Peak Demand, Installed Capacity, and Planning Reserve Margin (PRM)

Year	**Installed Capacity (MW)**	**Peak Demand (MW)**	**Planning Reserve Margin (%)**
2024	1924.96	936.02	105.7
2025	2016	989.89	103.7
2026	2107.03	1046.85	101.3
2027	2198.06	1107.1	98.5
2028	2289.09	1170.81	95.5
2029	2380.12	1238.19	92.2
2030	2471.16	1309.44	88.7
2031	2562.19	1384.8	85.0
2032	2653.22	1464.49	81.2
2033	2744.25	1548.77	77.2
2034	2835.28	1637.9	73.1
2035	2926.31	1732.16	68.9
2036	3017.35	1831.84	64.7
2037	3108.38	1937.26	60.5
2038	3199.41	2048.74	56.2
2039	3290.44	2166.64	51.9
2040	3381.47	2291.33	47.6

Figure 4 shows a line chart which displays the projected growth of both annual maximum peak demand and installed capacity from 2024 to 2040. A horizontal line representing the 52,000 MW (52 GW) target is included, starkly illustrating the significant shortfall of both projected demand and capacity relative to the Vision 2040 ambition.

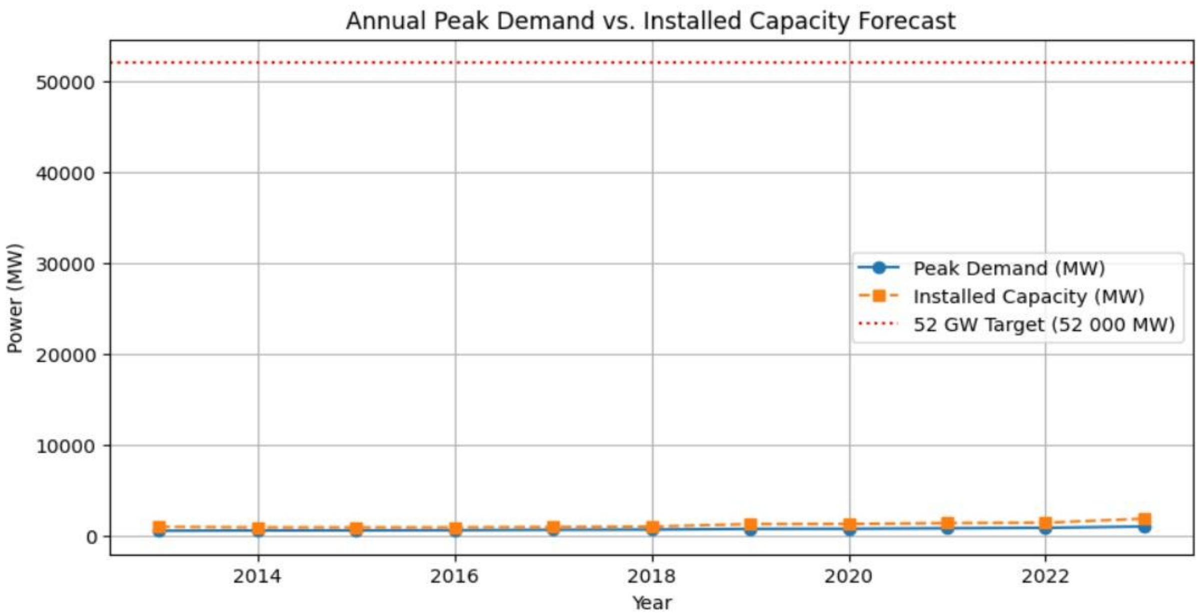

Fig. 4: Chart of Forecasted Peak Demand and Installed Capacity vs. 52 GW Vision 2040 Target

Discussion

The findings reveal a conspicuous and quantifiable disparity between Uganda's Vision 2040 energy targets and evidence-based forecasts. The statistical significance of the Time variable in the domestic and industrial models suggests that underlying socio-technical progress, such as gradual appliance adoption and technological modernisation, contributes to a steady upward trend in demand not fully captured by conventional economic indicators alone. Similarly, the significance of GDP and population in the commercial sector model confirms that economic development and demographic expansion are inextricably linked to commercial electricity demand, as rising incomes support the growth of retail and service industries.

The projected CAGR of 6.8% in this study is more conservative than earlier forecasts from national entities like ERA (7.5%) and UEGCL (8%). This difference can be attributed to this study's incorporation of the most recent data, which includes the demand slowdown during the COVID-19 period, and a more nuanced modelling of electrification progress, suggesting that earlier projections may have been overly optimistic.

The 52 GW target appears aspirational rather than an objective grounded in these projected trajectories. Pursuing such a target without a commensurate surge in demand would precipitate the development of stranded assets, imposing significant financial strain on the economy and likely necessitating higher electricity tariffs. This is a critical consideration, as high tariffs could suppress demand further, creating a negative feedback loop that undermines the very industrialisation the capacity was meant to support.

The primary policy implication is that investment in generation capacity must be strategically phased and linked to credible, data-driven demand projections. A flexible, demand-following investment strategy is required, prioritising modular and scalable generation technologies such as solar, wind, and small-hydro that can be deployed in response to verified demand growth. This approach mitigates the risk of over-investment while ensuring supply keeps pace with actual needs.

Furthermore, if the 52 GW target is to remain a strategic goal, it necessitates a paradigm shift from supply-side planning to aggressive demand stimulation. This would require transformative national policies aimed at rapidly expanding the industrial base, electrifying key sectors like transport and agriculture, and potentially establishing Uganda as a major regional electricity exporter through the East African Power Pool (EAPP). Without such profound interventions, the gap between ambition and reality will remain vast

Conclusion

A new study on Uganda's electricity sector concludes that the country's projected electricity demand by 2040 won't be enough to justify the ambitious 52 GW generation target set out in Vision 2040. The current growth rate is too slow, risking the creation of stranded assets and causing significant economic inefficiency. The research successfully analyzed historical data and developed forecasting models, highlighting a major gap between projected demand and the national targets.

Based on these findings, the study recommends a phased, demand-driven approach to generation planning, moving away from a fixed-target model. Instead of building a massive system all at once, new capacity, particularly from modular sources like solar PV and small hydropower, should be added only as demand truly grows. To help stimulate that demand, the government should implement targeted incentives for energy-intensive industries, like preferential tariffs and reliable power guarantees. Improving the existing grid infrastructure is also critical to reduce technical losses and ensure a reliable supply, especially in high-growth areas. Lastly, implementing Demand-Side Management (DSM) programs, such as time-of-use tariffs, could help manage peak loads and delay the need for new, expensive power plants.

For future research, the study suggests moving beyond simple forecasts to use probabilistic forecasting to better account for uncertainty. It also recommends explicitly modelling the effects of climate change on both hydropower generation and electricity demand. Finally, future national forecasts should include the increasing role of off-grid and decentralized power sources, like solar home systems and mini-grids, to provide a more comprehensive view of the country's total electricity consumption

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References

Atanane, A. L. B. & Atanane, A. E. O., 2023. Electricity demand forecasting: A systematic literature review, *IEEE Access*.

Energypedia, 2025. Uganda Energy Situation. https://energypedia.info/wiki/Uganda_Energy_Situation accessed on 25 July 2025.

Mirlatifi, A. M., 2016. *Electricity Peak Demand Forecasting for Developing Countries*. Eastern Mediterranean University.

National Planning Authority, 2013. *Uganda Vision 2040*. https://www.npa.go.ug/vision2040/ accessed on 25 July 2025.

Susaeta, A., et al., 2024. Determinants of electricity consumption in Sub-Saharan Africa: A panel data analysis, *Energy Strategy Reviews*.

Uganda Printing and Publishing Corporation (UPPC), 2024. Uganda's Effort to Meet Vision 2040 Power Target. *The New Vision*.

Umeme Ltd, 2024. *Uganda's Power Supply: Addressing the Debate on Excess Power*. Kampala, Uganda.